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REAL-TIME PSEUDO-RANDOM REPRESENTATION OF URBAN SPRAWL

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ABSTRACT (CONT.)

One approach to creating generic suburban terrain is to generate, in real-time, a feature set representing realistic suburban cultural entities in the immediate vicinity of player entities in a distributed simulation. A server could distribute these features as objects to client machines across High Level Architecture (HLA) or Distributed Interactive Simulation (DIS) interfaces. These features would include an assortment of houses, fences, utility buildings, pavement, trees, and other vegetation, objects, and structures combined to form an if-you've-seen-one-you've-seen-them-all-type subdivision of mathematically infinite dimensions. This same approach can also instantiate the internal structure of buildings when player entities come within immediate range, to allow entry and interaction between the interested entities and the internal features. The internal building layouts, exterior features, and variation in color and structure of these features could be large enough to be realistic but small enough to load the individual model representations onto legacy image generators. The entities themselves could be generated using an approach that ensures that instantiation of features will be totally repeatable but variable.

AMRDEC is developing the Pseudo-Random Urban Feature Entity Server (PRUFES) to demonstrate this approach. PRUFES uses a model set and rule set which together generate a generic suburbs known as "Protoville," an infinitely large suburb which contains a pseudo-randomly generated and complex network of streets, signs, lots, houses, vegetation, fences, parked vehicles, and other outdoor objects, as well as interior walls generated as needed for every house. PRUFES can supply suburban cultural entities across a DIS network for legacy terrain databases.

This report discusses the use of cultural entities for suburban representation, PRUFES design, and interoperability issues between cultural entities and legacy manned simulators and Semi-Automated FORces (SAFOR).

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I. INTRODUCTION

A. Urban/Suburban Problem Space

As the United States military becomes more interested in unconventional warfare, Military Operations in Urban Terrain (MOUT), and homeland defense, and as the U. S. Army transformation in particular is focused on developing an objective force with a broad range of capabilities from regional contingencies to full-scale warfare, the representation of urban and suburban sprawl becomes critical across the modeling and simulation domains of acquisition, requirements, training, and testing. Detailed representation of urban and suburban sprawl is required for acquisition and testing so that future military systems can be designed to perform effectively against the unique challenges brought about by complex terrain. Likewise, concept simulations and training simulations need extensive sprawl representations to define and train future urban tactics coupled with the generation of future operational capabilities. Systems such as the Army's Future Combat Systems will be expected to perform unconventional missions in sprawl areas as effectively as they perform in rural and sparse terrain.

The U. S. Army Training and Doctrine Command (TRADOC) Modeling and Simulation Advisory Council has identified the need for simulation representations of urban sprawl, and for the past year has kept an open action reviewing urban sprawl simulation capabilities. At the spring 2000 council meeting, the issue was still open, with no viable solutions identified. The need for terrain databases which incorporate building structures with interior detail is evidenced through the current proliferation of the virtual Fort Benning MOUT site, consisting of only a few buildings with limited internal structure, to all manner of simulation organizations. This need for suburban representations extends beyond TRADOC, throughout the Army and Department of Defense (DoD), and impacts directly upon the ability of the every military organization desiring to simulate urban combat.

The term "Urban Sprawl" depicts both dimensions of its own complexity, namely the high concentration of feature data in urban areas, and the expanse of this data across large surface areas of terrain. Urban and suburban terrain require detailed feature data to adequately describe complex Line-Of-Sight (LOS) obstructions, mobility barriers, serendipitous firing positions, civilian and commercial considerations, trafficability, and target acquisition clutter. This data cannot be limited to a small number of buildings in a minimal locale, but must be extensive and ubiquitous throughout a realistic battlespace.

Another key component of urban sprawl simulation is the need to represent internal building structure. Realistic urban warfare involves dismounted combat inside and outside multi-level structures. System designs and operational concepts based on oversimplified building structures will compromise effectiveness and training in actual urban terrain. Internal structure must include sufficient walls, doors, windows, and visual cues to provide meaningful interactions between manned and automated forces fighting within the structure, as well as those firing in and out building openings.

B. Traditional Limitations in Meeting Need

The combination of density, resolution, and expanse of the urban and suburban sprawl problem, coupled with the need to represent extensive interior structure, constitutes an unacceptable requirement when developing urban terrain in a traditional manner for implementation in legacy and new simulations. The traditional approach to representing urban terrain is the development of a new terrain database for each new set of requirements, based on either geo-specific or geo-typical source data, and is constrained in all dimensions by the amount of time and money that can be applied to the problem. This inevitably results in limited numbers of features with minimal internal structure. This approach also creates databases that may be overused or misused due to their limited availability, a practice which may compromise experimental and analytical results.

While some simulation applications require geo-specific terrain to support mission training, approved scenarios, live-virtual interaction, or battle reconstruction, many other applications may utilize geo-typical terrain to meet all experimental and analytical objectives. A primary example of the accepted use of geo-typical terrain is the live simulation capability hosted at Ft. Hood, Texas. While it is unlikely that a major military battle will occur at Ft. Hood, the terrain has provided considerable training for the Army to perform effectively in similar terrain. This same approach can validate the use of geo-typical terrain for constructive and virtual simulation.

The use of automated algorithms has been explored for generation of geo-typical terrain skin, water bodies, road networks, woodlines, and delineation of urban regions. These commercially available tools have undergone some criticism due to their competition with defense initiatives to collect geo-specific elevation and feature data in support of a comprehensive military requirement. Despite this criticism, these tools could expedite terrain database development to a certain resolution, but not to the degree required for the representation of urban sprawl, and not to the degree to generate internal building structures.

Another recent set of technologies with urban sprawl application is the evolution of rapid terrain generation techniques. This technology utilizes satellite or aerial imagery or radar range data to automatically translate phototextures and range maps into micro-elevation data, producing urban terrain databases superimposed with actual images. This technology has proven effective for aviation forces and some route planning and mission planning applications, but does not produce sufficient resolution for dismounted warfare, nor does it address internal structure. These terrain databases still require considerable manual refinement to deal with non-rectified images, shaping overhanging structures, and delineating between terrain skin and feature data due to ambiguities in first reflective surfaces.

Assuming that through some combination of new technologies and raw manual effort, a database of sufficient expanse, complexity, and resolution could be developed for use in legacy and new manned simulators and constructive simulations, the next technical issue would be the ability of the individual simulations to store, load, manipulate and render these database files in real-time. Simulations built to accommodate and utilize these large files, if possible, would require

premium storage, computational and image generating capacity, a level of capability seldom affordable in support of the simulation of dismounted warfare.

Further, assuming that this ideal database could somehow be both built and rendered, it could now be applied to a number of urban and suburban battle simulation uses, giving total freedom of movement and flexibility in use for each mission, with sufficient variability to prevent "learning" the scenario and terrain to produce negative training or erroneous analysis. Sadly, even the most extensive use of this perfect database would not begin to utilize every feature and detail in the expanse of terrain, when we consider including the interiors of all the structures. This fact does not diminish the requirement for terrain detail and complexity, since all this data would be needed a-priori to permit freedom of movement to the executing force in the experiment. But after the fact, the level of effort and cost required to generate substantial detail that was never utilized is an extremely inefficient solution.

II. CONCEPTUAL MODEL OF A CULTURAL ENTITY SERVER

An ideal approach to generating terrain detail is to do so on-the-fly, when and where it is needed by player entities. Terrain features that are automatically generated and distributed from a common server could be provided in real-time to all simulations in the architecture, multicast to only those players who need the respective objects, then dropped from reference, freeing dynamic memory, as they are out-of-sight and out-of-mind. This approach is the equivalent of Guttenberg's printing press, requiring the development of individual letters rather than unique pages of text, the combination of those letters forming the variations needed for any requirement. Real-time generation and distribution of cultural features allows the construction of virtual cities and suburbs the way real ones are built, through re-use of basic designs, styles, and materials, in keeping with mathematical rules, cultural norms, and zoning regulations.

Conceptually, the cultural entity server could be used at any level of abstraction, but the current level of object instantiation should probably correspond to the "platform" level of entities that are typically used in distributed simulations. Likewise, a cultural entity server could draw from geo-specific feature data in a master database, but a sufficiently comprehensive database will not be available in the immediate future, as was previously discussed. These points suggest that the best current application of the cultural entity server is in the generation of geo-typical terrain features, where the "letters" consist of buildings, trees, streets, signs, fences, parked vehicles, etc. These letters must be ordered into sentences based upon a rule set that provides a balance of variation and structure so that the terrain that is generated is realistic, but not predictable.

The same methodology that generates individual buildings and other outdoor objects may also be used to generate interior building structure as needed. As player entities approach any individual building, the interior walls may be published as an object or group of objects so that the player may interact with and be obstructed by this interior structure.

In order to be of use, the cultural entity server must be able to reproduce identical object sets whenever a region is instantiated during an exercise, or over a series of integration tests, planning sessions, and exercises, whenever continuity is required. If structures are allowed to be vulnerable to damage or change of state, those states must be saved and reproduced whenever the features are re-instantiated.

A cultural entity server may be defined by three parameters: the interfaces to the simulations it services, the rule set for calculating and publishing entities, and the model set provided to target simulations for rendering the published objects. Once the interfaces are defined, the server can be used to generate numerous types of urban and suburban sprawl based upon the configuration of the second two parameters; the rule set and the model set.

A. Service Interfaces

The use of a real-time server solution lends itself to application of the Distributed Interactive Simulation (DIS) or High Level Architecture (HLA) standards. While DIS purists may argue that any server concept violates the premise of distribution of functions across all players, the practical use of servers in DIS applications is extensive and effective and has allowed DIS to continue to be a viable standard for a variety of simulation applications. HLA allows further flexibility than DIS, but the interface approach can be very similar. Other distributed architectures such as Aggregate Level Simulation Protocol (ALSP), which are not based upon entity-level simulation, are not appropriate solutions.

In a DIS application, the server would monitor the entity state Protocol Data Units (PDUs) of player entities and would broadcast entity states of all cultural features in the immediate vicinity of all the players. Architectures could be designed with PDU filters to allow localized distribution of cultural features from multiple servers to help reduce bandwidth usage, but the multiple servers would have to be identically configured to generate the same pseudo-random features in the same locations.

The DIS entity state provides appearance bits and articulation fields which could be used to provide variability to models and unique markings for houses and road signs. Also, image generators may use levels of detail to render different visual models based upon range. These levels of detail could be used to trigger or render details in building exteriors, or the visual image of interior structure.

Legacy DIS simulations typically set a time-out for entity states so that entities which have fallen off the network are eliminated from their local lists. This mandates a “heartbeat” of typically five seconds or less to sustain entity presence on the network. When generating large numbers of static entities, this heartbeat can unnecessarily increase the data on the network by orders of magnitude. If all simulations on the network are disciplined about generating “last PDU” data when an entity is removed from the net, then time-outs can be extended or eliminated, allowing drastic extension in the required entity state heartbeat for cultural features.

Using HLA, entity attributes could be published in a more structured way, multicast to subscribing simulations based upon player object locations. HLA could provide more variability in appearance switches and states than DIS, provided that the other simulations in the HLA federation all utilized those additional parameters. In a practical sense, most near-term uses of HLA for cultural entity servers would probably utilize the Realtime Platform Reference (RPR) Federation Object Model (FOM) for compatibility with legacy DIS simulations.

B. Rule Sets

The second defining parameter for generation of cultural entities is the implementation of rule sets to dictate the layout, appearance, and instantiation of the features. All rule sets are integral to the urban feature server. Some rules place requirements on the user and allow user input for limits, averages, or other parameters, while others will be hidden from the user. Many of the rules will involve random number draws to determine layout design selection, model selection, appearances, and whether or not an entity will be instantiated. Rules must be defined so that an urban area can be recreated by using the same random number seed.

Rule sets determine *what* features will be placed *where*, and *when* they will be instantiated. Rules are based upon the geo-typical parameters of the region to be rendered, including road networks, lot layouts, house locations, vegetation density, and existence of other outdoor features such as fences, signs, traffic devices, and other objects of interest. A small number of rules in series can generate a great deal of variability in the terrain.

C. Model Sets

The outcome of the rule sets will define which cultural feature models are broadcast by the server. Thus, each player simulation must be provided a set of textured geometric models for rendering the cultural feature entities. The models will determine *how* the feature entities will appear to image generators in manned simulations and visualization tools. Models may be divided into several cultural feature categories and each given a type value defined by the entity server developers. Models may incorporate levels of detail, appearance switches, and articulated parts to achieve all the possible results defined by the rule sets.

A typical model set might include a dozen houses, each with several appearance options for exterior texture, several tree and other vegetation models, models for street segments, fences, and any other entity that the rule set may require.

At issue is the way many constructive simulations use icons and bounding volumes rather than Three-Dimensional (3-D) representations of features, and what type of model set might provide an adequate solution. These simulations will not currently calculate LOS and interaction with cultural entities properly, especially for internal structure, without significant modification to enhance their detailed understanding of entity structure.

III. A PROTOTYPE APPLICATION

A. The Pseudo-Random Urban Feature Entity Server (PRUFES)

The U. S. Army Aviation and Missile Command (AMCOM) Research, Development, and Engineering Center (AMRDEC) is developing the Pseudo-Random Urban Feature Entity Server (PRUFES) to demonstrate the cultural entity server approach in order to meet the analytical needs of the center for urban/suburban sprawl representation. PRUFES uses a model set and rule set which together generate a generic suburb known as "Protoville," a mathematically infinitely large suburb which contains a pseudo-randomly generated and complex network of streets, signs, lots, houses, vegetation, fences, parked vehicles, and other outdoor objects, as well as interior walls generated as needed for every house. PRUFES can supply suburban cultural entities across a DIS network for legacy terrain databases, with a corresponding model set.

DIS was selected over HLA as the architectural interface for PRUFES, primarily on the prototypical nature of the tool. PRUFES was designed to work with legacy DIS simulations without the need for a gateway, for expedient use and for baselining performance of large numbers of static entities on the network without inserting the additional uncertainties surrounding HLA run-time infrastructure and gateway latencies. Once operational and baselined in support of legacy DIS simulations, upgrade to a native HLA interface is anticipated.

B. Protoville

The first PRUFES application, based upon an initial rule and model set, is a suburban area called "Protoville." Protoville represents a typical all-American subdivision using the if-you've-seen-one-you've-seen-them-all design approach (Fig. 1). The rule set for Protoville is a combination of templates and random number draws to select variable combinations of entity types and positions (Fig. 2).

Special modeling techniques have been used in developing the model set for Protoville. The buildings and other structures contain extended foundations or skirts and linear features such as road segments and driveways have thickness. These techniques were used to reduce visual anomalies when rendering the cultural feature models on an underlying terrain that is not perfectly flat.

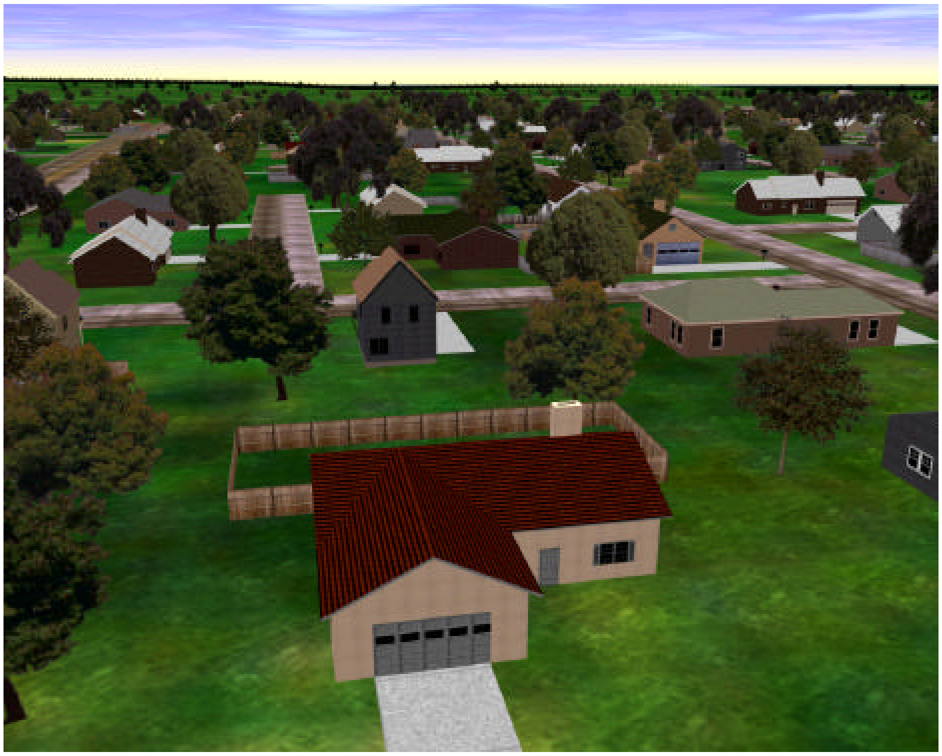

Figure 1. Protoville, a Typical American Neighborhood

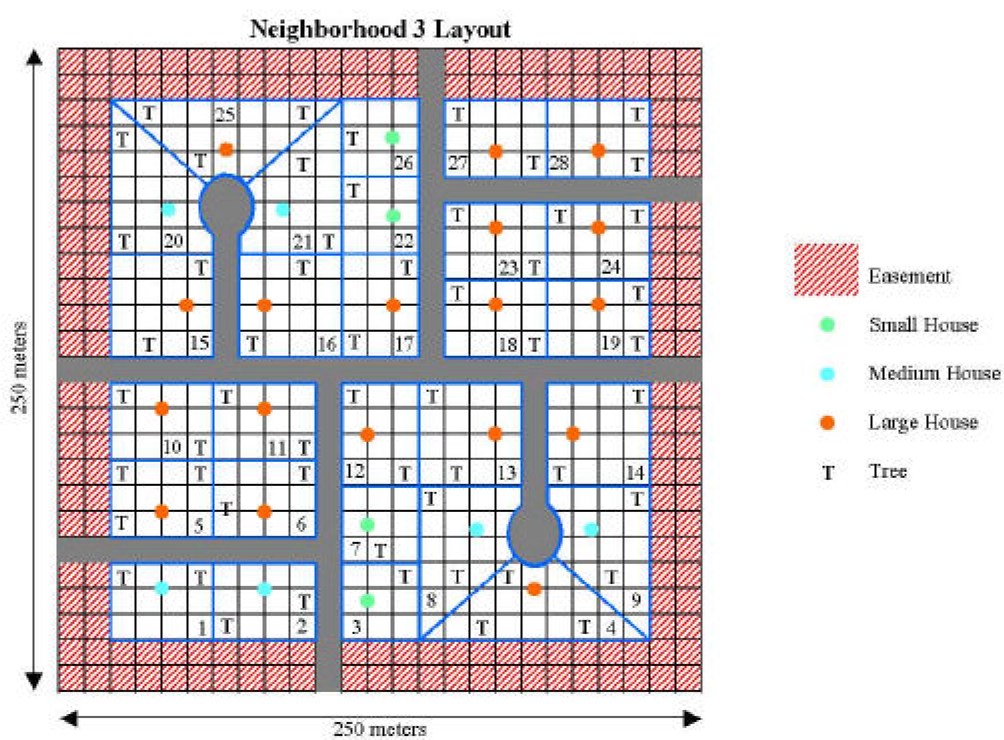

Figure 2. Sample Lot Layout

C. Integration, Interoperability, and Performance Issues

The main objective of PRUFES is to serve cultural feature entities to simulate urban/suburban sprawl to legacy and future simulations. The cultural entities generated by PRUFES must be recognized and utilized properly by the other simulation players. PRUFES uses the standard DIS enumeration bits to define cultural feature entities. For all PRUFES entities, the DIS entity kind bit value is 5, which is defined as "cultural feature." The domain is 1 for "land" and country is 0 for "other." The category, subcategory, specific, and extra bit values use some existing and some newly defined values to describe all the cultural feature entities used with PRUFES.

Unfortunately, many legacy simulations do not accept entities that are of DIS kind "cultural feature." This fact has been verified by a number of integration tests with legacy simulation visualization systems and constructive simulations. These simulations often filter cultural entities when they are received on the network, or treat them inappropriately within the simulation. Therefore, a legacy simulation claim of "DIS compliance" does not mean that the simulation treats the full compliment of DIS entities properly.

These integration tests also found issues with some simulator systems which are built around ModSAF libraries. The use of these libraries currently puts limitations on the simulation's ability to add new entities to the enumeration list and to associate a 3-D model for each new entity because these changes require editing source code and recompiling software.

Early testing demonstrated that ModSAF avoided cultural features because of collision avoidance algorithms. This is the appropriate behavior for most entities, but with PRUFES, appropriate behavior is for players to walk or drive on the PRUFES-generated road segments and enter into houses and buildings. Each simulation needs to have the ability to do selective collision avoidance based on the type of entity.

Another issue was discovered in simulation LOS calculations. Most legacy simulation systems only use terrain feature information in LOS calculations. With PRUFES, the cultural entity information also needs to be included when calculating LOS.

A common limitation in legacy simulations is a lack of ground clamping capability. Ground clamping over-rides the default elevation data provided over the net and forces the entity onto the underlying terrain. The current version of PRUFES requires all client simulations being served by PRUFES to ground clamp unless the underlying target terrain is perfectly flat.

Simulations also need to have the capability to change the timeout threshold for incoming entities. Tests have shown simulations timing out due to the fact that PRUFES entities are static and therefore send out fewer updates to minimize network traffic.

The most significant interoperability issue between PRUFES and other simulations, whether they are constructive, semi-automated forces, or manned simulators and virtual prototypes is the ability to interact with the interior structure of buildings. The challenge to the PRUFES user is to recognize the interior structure of a building being broadcast as an entity and

to then interact with the walls and doors appropriately. Some existing simulations have the capability to interact with interior structures, but this behavior is limited to specially encoded information compiled into their respective terrain databases. The first step in solving the problems with interiors is to apply the functionality used with structures that are compiled into a database to cultural feature entities generated by PRUFES.

The main performance issue associated with using PRUFES to simulate urban features, rather than building them into the terrain database, is the sheer number of entities in a concentrated area and the amount of network traffic created when publishing the entity information to the clients. Each 250m x 250m neighborhood is made up of nearly 200 entities. Since the smallest area that can be populated is 500m x 500m, there could be nearly 800 entities in this concentrated area. Managing and displaying this number of entities may be difficult on some legacy simulations. System performance suffers due to the ground clamping requirement; however, some simulations allow for ranges and filters to be set for ground clamping to minimize the performance degradation.

In summary, these issues and interoperability problems exist for the most part simply because the real-time generation of cultural entities was unanticipated by legacy simulations. Most of these simulations could become compatible with cultural entities with minor modifications, and future simulations could be designed with full cultural feature interoperability. Legacy simulations nearest to “plug-and-play” with no modifications are those man-in-the-loop virtual simulations that display 3-D visual models of entities and rely on human target acquisition and player movement. Fortunately, these are also the types of simulators that are best suited for the simulation of dismounted combat.

IV. EXTENDED FUTURE APPLICATIONS

PRUFES is a prototype system, designed to provide basic suburban sprawl capability while demonstrating the potential for a more robust cultural entity server solution. A number of enhancements could be made to PRUFES, or included in a next-generation feature server, to increase utility and interoperability. These might include:

- Additional types of cultural features to achieve more realism in the simulated urban/suburban area, such as the ongoing development of more neighborhood layouts, increased random variation, and larger model sets for Protoville in PRUFES, allowing for more variation and randomness in the population of features.
- Additional geo-typical rule and model sets representing various domestic and foreign regions as well as different appearances for models to provide seasonal changes to the cultural feature environment.
- Additional rule and model sets representing different types of urban sprawl, such as warehouse districts, low-income housing, docks and port facilities.
- Acceptance of user input for parameters such as entity density, allowing end-users to tune performance to their individual requirements.
- Ability to read or reference elevation data within the entity server to eliminate the requirement of ground clamping. This would also require increased sophistication in model development and orientation to place features properly on irregular or sloped terrain.
- Ability to define non-rectangular, complex regions to populate with cultural entities, including no-go areas such as mountainous areas, waterways, or geo-specific feature areas that are modeled into the terrain.
- Native HLA interfaces with increased interactions and attributes published to federate simulations.
- Ability to generate non-static entities with scripted or reactive routes and behaviors.
- Ability to calculate and generate damaged cultural features based on player actions or scripted activities.
- Ability to simulate and publish multi-story and complex internal structure to buildings.

Incidental and supplemental tools could also be developed in support of real-time feature generation. Tools will be needed to pre-view neighborhood layouts and feature placements for experiment control. Other tools could be developed to generate Two-Dimensional (2-D) neighborhood overlays for constructive simulations and computer generated forces, and to save and print feature maps. Offline feature generation tools could be of use to non-real-time

simulations, and to terrain database developers. Data collection tools will also be needed for experiment control, performance benchmarking, and battlefield statistics.

Lastly, the concept of nested detail in real-time generation of features, as is demonstrated when internal structure is generated as needed for player entities approaching a building, could be expanded to achieve an n-level effect of quantized resolution. This effect could allow instantiation of increased detail in precise locations as those locations have the potential to be observed.

> *For example*, as a player entity approaches a house, the internal walls are instantiated. As he approaches the kitchen, the cabinets come into existence. If the player opens a cabinet door, the cans of food appear, and if he opens a can, so arrive the beans.

If this scenario appears too unlikely, consider a homeland defense mission that requires a soldier to enter a series of buildings with a chemical detector and determine which ones are contaminated with a lethal agent. He might very well perform actions similar to those described above. If we give the soldier a microscope and change the experiment, we may require even deeper layers of nested detail.

V. CONCLUSIONS

Real-time generation of pseudo-random cultural feature entities has the potential for solving a number of urban/suburban sprawl requirements. The proposed concept solution enables mission flexibility and complexity, terrain re-usability, low-cost urban/suburban terrain generation, and rapid feature variability. This capability is provided at some expense in terms of network traffic and scene generation latency, and does not lend itself to geo-specific terrain. This performance trade-off is only viable for those simulations whose developers are willing to modify their products, if necessary, to accept and utilize cultural feature data properly.

Given that major or minor investment, PRUFES or some other cultural entity server, integrated with one or more player simulations, can provide viable simulations of urban/suburban sprawl. This has already been demonstrated with stealth viewers and virtual prototypes of advanced battlefield systems, and will continue to evolve as other simulations are interconnected and proved to interoperate, and as cultural entity server technology and capabilities improve.

AMRDEC will continue to develop and utilize PRUFES in DIS and HLA simulation federations in support of customer requirements and MOUT experimentation, and will continue to modify legacy simulations and develop new ones for interoperability with real-time generated features.

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